FISSURE SYSTEMS AND MINERALISATION IN CORNWALL

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I. RELATIVE AGES OF THE FISSURE SYSTEMS OF CORNWALL

Since very early times the lode miner in Cornwall has been very aware that the fissures which he encountered were of varying ages. He knew only too well that there existed certain fissures, containing usually only quartz or fault clay, which were formed later than the valuable tin and copper lodes, and which displaced them, and in so doing caused him a great deal of trouble. These usually barren fissures he termed cross-courses, cross-flucans, and slides.

By the beginning of the nineteenth century a great deal of information regarding fissure phenomena was available, and from that time to the present, several theories regarding the relative age of formation of the various filled fissures were put forward. Thus, in 1818 Joseph Carne divided the Cornish fissure lodes in the following eight classes :—

1. The oldest tin lodes, mostly underlying northwards.
2. More recent tin lodes, mostly underlying southwards.
3. Oldest east and west copper lodes, mostly with a northerly underlie.
4. Contra (or caunter) copper lodes.
5. Cross-courses, bearing generally within 20 degrees of north
6. More recent copper lodes.
7. Cross-flucans.
8. Slides.

At about the beginning of the twentieth century Collins classified the Cornish fissures as follows, but added that probably many more classes existed, which have not, on account of their lacking economic importance, been recorded by the mining fraternity :—

1. Faults of the granite junctions.
2. The older elvans (i.e. porphyry-dykes).
3. The oldest tin lodes.
4. The newer elvans.
5. The older tin lodes.
6. The older tin and copper lodes.
7. The newer tin lodes.
8. The older caunters (essentially copper and tin lodes).
9. The older cross-courses and flucans (usually carrying quartz and clay, frequently lead and siderite, and occasionally copper).
10. The newer east and west lodes (copper with tin in depth).
11. The newer caunters (usually lead, zinc and iron, but occasionally copper).
12. The newest east and west tin and copper lodes.
13. The newer cross-courses and flucans (quartz and/or fault clay but occasionally iron).
14. The newest flucans and slides (fault clay).
15. Alluvial faults (i.e. those which have formed since the deposition of the alluvial tin deposits).

As the twentieth century progressed, it came to be realised both in Cornwall and elsewhere, that metallisation associated with granite was simply the last phase of intrusion which took place under progressively diminishing temperature conditions and was brought about by magmatic material which became more and more impoverished in granite material and consequently more and enriched in the residual mineralisers.

There was also abundant evidence that such minerals as cassiterite, wolfram and tourmaline were formed under conditions of high temperature and pressure, whilst minerals such as galena and siderite were formed under conditions of more moderate temperature and pressure. Such indications as the multi-stage brecciation and mineralised complexity of many lodes also indicated that there was progressive faulting throughout and later than the period of mineralisation. Also it was held that no granite was emplaced after the commencement of dyke formation.

Because of the above it was held that Collins' classification was inaccurate since it indicated that some porphyry dykes were formed later than some of the tin and copper lodes, and that lead and siderite had been formed earlier than some of the higher temperature cassiterite. The opinion was that Collins had made these errors because he had laid too much stress on strike of lodes, and on lode fillings. It was argued by later workers that within a small piece of lode hypothermal and mesothermal materials might exist side by side simply because the latter had been deposited on the re-opening of the lode at a time when the temperature had decreased.

Up to about the thirties of this century the Cornish sequence of metallisation, etc., was believed to be as follows :—

1. Emplacement of coarse granite, followed, or accompanied by emplacement of finer granite.
2. Development of joints in the granite by contraction and extension of these into the country rock.
3. Movement under gravity along these joints, especially the E.N.E.—W.S.W. ones, causing the development of fissures which were infilled with porphyry dykes.
4. Development of quartz-tourmaline veins, quartz veins, aplites, granite pegmatites, (and possibly far from the source, minettes).
5. Development of metallised pegmatites carrying especially wolfram but also some cassiterite.
6. Development of the "normal" hypothermal tin-copper-tungsten lodes (these being in many cases developed along E.N.E.—W.S.W. lines and therefore coinciding with the strike of many of the dykes and of one set of master joints in the granite).
7. Development of the lead-zinc-iron lodes, usually along roughly north and south lines.
8. Development of the barren fissures carrying only quartz and/or fault clay, known variously as cross-courses, cross-flucans and slides, and also striking generally in a north and south direction.

Whilst the sequence granite, dykes, granite pegmatites, metallised pegmatites, tin-tungsten-copper lodes, lead-zinc-iron lodes, barren fissures, is generally correct as far as Cornwall is concerned, yet there is evidence to show that this represents an over-simplification of the case, and that evidence is as follows :—

1. Ghosh has shown that the Carn Menellis mass is made up of three distinct granite intrusions and that associated with the first are quartz-tourmaline veins and masses of pegmatite ; with the second, felspathic veins, pegmatites and quartz-tourmaline veins ; and with the third, aplites, porphyry-dykes and quartz-tourmaline veins.

2. Emmons has stated that whilst the larger and metalliferous pegmatites immediately precede the formation of the metalliferous lodes in time, yet pockets of barren granite-pegmatite are formed late in the consolidating granite cores, and beneath the level of productive lodes. Small pockets of this class have been observed by the author in De Lank quarry. However, if Hulin is correct in his theory, which is discussed later, these pockets were formed before the lodes.

3. Although it is generally held that the porphyry-dykes are never earlier than the earliest granite with which they are associated in Cornwall, the author of the Lizard and Meneage Memoir (1946) discussing the southern portion of the Carnmenellis mass, says that some Cornish porphyries may possibly be older than the major granite intrusives. He does not, however, give any reasons for this statement.

4. Collins, who was an accurate observer, has stated that at Great Wheal Fortune, in the parish of Breage, a swarm of tin veinlets, known as the "Conqueror Branches" has been distinctly cut by a porphyry dyke and displaced by it.

5. Henwood has stated that at Wheal Vyvyan (Constantine), veins of granite sometimes cut off the small strings of copper and tin ores 'throwing them upwards."

6. Both Hawkins and Henwood reported that at Polgooth porphyry dykes clearly intersect lodes as well as other porphyry dykes. The validity of this example has been doubted by those who wrote the Bodmin and St. Austell Memoir, because certain plans of this mine are contradictory. In connection with 4, 5, and 6 above the following statement due to Hulin, an eminent American geologist, is of interest

—"The mineralisation (associated with major acid intrusives) ordinarily follows the igneous activity, frequently being entirely later, but occasionally overlapping in time."

7. Dines has produced a section of the quartz-wolfram pegmatitic lode at the No. 4 level of Castle-an-Dinas mine, St. Columb, in which granite apophyses are distinctly seen to penetrate the lode, and must therefore, be later than the lode. At the Museum of the Royal Cornwall Geological Society, Penzance, a specimen from this mine shows a portion of a fine-grained granite tongue bordered on each side by quartz and wolfram, and in the midst of the granite is a wolfram "xenolith." That this is a somewhat anomalous lode is further indicated by its roughly N.-S. strike and the fact that it locally carries a considerable quantity of lollingite, a mineral not known to occur elsewhere in Cornwall. The roughly N.-S. tin veinlets of Mulberry openwork, the N.-S. lode of Rock Hill, the N.-S. leader of the Park of Mines, and the N.-S. Watergate Bay porphyry may all be associated with the Castle-an-Dinas phase of mineralisation, as they all occur in the same part of the county.

8. At South Crofty mine, wolfram, which was found in a fairly well defined zone in the intermediate levels of the mine, has again, after passing through a wolfram-barren zone, been encountered in the deepest levels of the mine. This has been discussed elsewhere, and therefore it is sufficient to say here that we may be dealing with a second period of mineralisation, possibly separated from the first by a period of granite intrusion. Therefore the history of this area may be similar in some respects to that of the Castle-an-Dinas area discussed above.

II. STRUCTURAL CHARACTERISTICS OF THE CORNISH FISSURES

Fissure lodes, barren veins and porphyry dykes are similar in that they vary considerably in length and width, may or may not branch, and each individual may exhibit variatiations in its strike and dip.

In any given area it is usual to find a series of lodes striking along lines roughly parallel to each other and to any porphyry dykes which may be present ; and another later series of fissures striking along lines roughly at right angles to the earlier lodes and dykes, and frequently displacing them. Finally, there is overwhelming evidence to show that lode fissures and the barren cross-courses fissures are fault fissures, but whether or not the porphyry dykes occupy fault fissures is a matter of doubt, although the author is inclined to believe that it is the case.

The structural characteristics of the fissure lodes are as follows :—

1. **Length.**

As in many other lode-mining regions of the world, the Cornish lodes and barren fissures show great variation in length. Many of the lodes have been traced for a distance of three miles along their strike, and some considerably farther. Thus, for example, both the Great Flat lode, Carn Brea, and the Dolcoath Main lode, extended for three and a half miles whilst the Old lode of the United Mines, Gwennap, extended through Carnkie to Camborne, a distance of seven miles. Many of the cross-courses are several miles long and one of the longest extends from Wheal Alfred, Gwinear, to Wheal Fortune, Breage, a distance of eight miles.

2. **Breadth of Lode Fissures.**

It is important to realise that the breadth of a lode may have little or no connection with the breadth of the fissure associated with it, and along which the "lode forming" solutions and/or vapours originally moved. Thus for example, the rich pipe-like lode of East Wheal Lovell was associated with a fissure which varied from a knife-edge in thickness to about two inches ; the fissures associated with the Dolcoath Main lode was often very narrow, as are those associated with the great tin-bearing carbonas in the St. Ives mines. The breadth of a fissure commonly varies along its strike, frequently being reduced to exceedingly small dimensions and this was well shown by the very narrow fissures connecting some of the ore shoots of the Great Flat lode.

Frequently also, the breadth of a fissure varies along its dip, a fact considered by Moissenet to be due to fractures developing across rocks of varying physical properties, and followed by faulting along the planes of fracture.

Fissures associated with tin-copper-tungsten minerals are usually less than a foot in breadth, and often only an inch or less. Usually then, the values have been formed by metallisation of the country walls, although valuable deposits are known, such as the greisen-bordered tin-wolfram veins of Cligga and the tin stockwork of Mulberry (Lanivet) where the riches are largely confined to the fissures. In these cases the fissures are about one or two inches wide in the former and a fraction of an inch in the latter, and it is only the great numbers of fissures present in a comparatively small volume of ground which gives such deposits an economic value. On the other hand, the lead-zinc-iron deposits of Cornwall are found practically entirely within fissures, and these often have considerably greater breadth than any met with in association with tin-wolfram lodes. Thus, for example, the Mary Ann Trelawney lode varied in width from two to six feet ; the Herodsfoot lode from a mere joint to about four feet ; the lode of the Garras Mine (3 miles north of Truro) was from two to six feet wide ; and William's lode of Wheal Chiverton was from two to six feet wide. All these were lead lodes and the values were entirely confined between the fissure walls.

The maximum breadth of the late formed cross-course fissures varies from a mere fraction of an inch to many feet. Thus, for example, at Wheal Virgin, there was a cross-course two feet wide, at Wheal Sparnon a cross-course eight feet wide, and at Wheal Squire a cross-flucan (i.e. a fissure filled with fault clay) two feet wide. Because of the fact that many cross-courses are nearly vertical, their breadth often varies very little over considerable vertical depth.

3. Faults and Related Phenomena.

Although most of the Cornish lodes clearly indicate that they are associated with fault fissures, there are some in which such evidence is obscure or totally lacking. There is also little direct evidence to show that the porphyry dykes occupy fault fissures, and indeed Andersen is of the opinion that dykes rarely occupy fault fissures : "There is thus, in general, no lateral and no vertical displacement (i.e. produced by dykes) the latter being well-known to coal-miners. Exceptions to this rule are met with, but probably only when a dyke has occupied a pre-existent fault."

Some scanty evidence indicates that the Cornish porphyries may occupy fault fissures, e.g. : the Conqueror Branches have been displaced by a porphyry dyke at Great Wheal Fortune (Collins) : and some believe the lodes of Polgooth to have been displaced by a porphyry dyke. The occasional occurrence of xenoliths of country rock in the dykes such as one finds, for example, in blocks of porphyry on the top of Carn Brea, is no real evidence of faulting. It is probable that the throw of any given fault decreases to the left and right when traced along the strike from the point of maximum displacement. Quite what happens at the extremities of a fault fissure is unknown because if the fissure were associated with valuable minerals, these invariably became impoverished when followed laterally and were abandoned by the miner long before the fissure had disappeared. It has been suggested by MacAlister that fissures in the granite might tail off into ordinary granite joints, and in the slate into cleavage planes and joints.

The evidence that the lodes occupy or are determined largely by fault fissures, and the effects of faulting is seen in the following phenomena :—

(i) Slickensides. Almost any large mine dump will supply specimens of slickensides and MacAlister saw slickensides in situ at Cooks' Kitchen mine where at the 270 fathom level the granite footwall of the Highburrow lode was scratched up and down for several fathoms, and at the 210 fathom level at Dolcoath where horizontal striations were found associated with the Main lode.

Others have recorded the presence of numerous slickensides at Wheal Uny, Great Wheal Fortune and a host of other mines, while Ghosh has noted the presence of slickensides on the joints of Carnmenellis granite, which indicated that in some instances lateral as well as vertical displacement had taken place.

It is indeed probable that a certain amount of lateral displacement almost always accompanies vertical displacement during faulting.

(ii) Brecciation. Portions of brecciated lode material may be found on a great many of the mine dumps in Cornwall. The author has, for example, found fragments of quartz cemented by later quartz, chlorite, and pyrite, at Wheal Buller, Redruth ; chloritic slate cemented by siderite and galena on the small dumps at Watergate Bay ; and a specimen from Perranuthnoe beach showing angular fragments of chloritic-slate first cemented by quartz and then shattered again and recemented by siderite. This last specimen is quite a nice illustration of the fact that many lodes of Cornwall have been shattered and recemented on several successive occasions.

Both mesothermal and hypothermal lodes in Cornwall show brecciated structures frequently, but whereas in mesothermal deposits the breccia is found within the fissure, in hypothermal deposits it is often the walls that have been brecciated and recemented. Cronshaw noted that in the hypothermal deposits of the "greater" Camborne district the intensity of brecciation decreased in depth below the granite-slate contact.

As further examples of mesothermal deposits which show brecciated ore, one can cite the lead lode of the Redmoor mine near Callington, which is made up of fragments of bleached slate cemented by galena and siderite, and the Great Perran iron lode which has supplied magnificent specimens of limonite cementing angular quartz fragments.

Amongst hypothermal deposits showing fragments cemented by later minerals may be mentioned the peculiar lode of Relistian, Gwinear, where rounded fragments of dark slate were cemented by quartz, chlorite and cassiterite. In the Camborne-Redruth district most of the cassiterite lodes show marked and sometimes successive brecciation. Thus the lodes of the King Edward mine appear to have had the following history :—

(a) Opening of a fissure and invasion of quartz.

(b) Re-opening of the fissure and brecciation of the quartz, then introduction of quartz, tourmaline and cassiterite.

(c) Re-opening of the fissure and brecciation of the contents, then introduction of quartz, chlorite and cassiterite and possibly some sulphides.

(d) Brecciation of the contents and introduction of quartz, chalcopyrite and pyrite.

Sometimes the fracturing due to movement followed by cementation of the fragments is only apparent when a thin slice of the lode is examined under the microscope. Thus, for example, apart from an often not too apparent variation in width of any given lode in the Cligga granite, the only certain evidence of relative movement of the lode walls is indicated by shattered quartz and cassiterite crystals seen in thin sections.

Similarly a slide prepared from the North Pig lode, Number 10 drive at Geevor Mine (St. Just) and examined by the author was seen to consist of the gangue of quartz and corroded felspar and to contain cassiterite, which had been shattered and recemented by chalcopyrite.

Complete information of such finely brecciated ore is obviously of extreme importance to extraction metallurgists. In the case cited, for example, grinding to a mesh which would largely liberate the cassiterite from the cementing chalcopyrite is obviously necessary before removal of the sulphide by flotation is resorted to.

It is to be noted that according to Cronshaw many Cornish lodes which have been repeatedly re-opened, may, during some of the re-openings have been brecciated and during others remained free of brecciation, and that when a lode showing such phenomena is examined, it is usually found that brecciation was associated with the earlier re-openings and lack of brecciation with the later re-openings.

(iii) Fault Clay (flucan or gouge). Many fault fissures contain little or much fault "clay" derived as a result of their movement of their walls over each other. It is probably more frequent in the shallow than in the deeper parts of lodes, and Moissenet believed that the more homogeneous the rock the more likely it is that fault clay rather than fragments will develop.

Sometimes this clay is found lining the fissure walls, sometimes as thin partings parallel to the walls and indicating repeated re-opening of the fissures in question, and sometimes largely filling the fissure.

At Wheal Uny the "leader" (i.e. the fissure along which metallising solutions moved) was occasionally only a fissure about two inches wide filled with clay and a little quartz.

Occasionally fault clay constitutes almost the whole of the gangue in a vein ; thus at West Chiverton the silver-rich galena was often dispersed through a clayey matrix.

Many of the late formed fissures (the cross flucans) are almost entirely filled with fault clay.

(iv) Drag of faults and related phenomena. Movement along a fault plane may cause flexures in the country rock in the immediate neighbourhood of the fissure, and this phenomenon termed "drag" has been developed near some of the Cornish fissures. Thus at East Carn Brea mine a number of small porphyry dykes occur which are traversed by lodes, and near the lodes both dykes and slate are bent in such a way that they are tilted up on the hanging wall side and down on the foot wall side. At Wheal Kitty (St. Agnes) and at the Duchy Peru Mine (Perranzabuloe) the slate is sometimes dragged in the region of the lodes. At Ventonwyn mine (St. Austell) the cleavage planes of the slates is nearly horizontal, but near the main lode the dip of these cleavage planes gradually increases until they become parallel to the lode. Along the coast section between Porthleven and the Loe Pool is to be seen a mineralised fault dipping steeply south : and near the lode the slate has been dragged down.

Sometimes as a result of tension developed by friction as the hanging wall of a fissure moves under gravity, the hanging wall, instead of developing drag phenomena of the type already described, may become very fractured, with the resulting production of a stockwork or simply a brecciated structure, or may develop a few steeply dipping branches, or may open up cleavage planes, especially if they dip steeply into the parent fissure. However, sometimes the greater results of movement are to be found in the foot wall. Thus a portion of the No. 1 lode at South Crofty when examined by Cronshaw showed brecciation chiefly in the foot wall. The Towanrath lode at Wheal Coates, St. Agnes, had a beautiful stockwork in its hanging wall, and it was here that most of the values were found. The country rock is a fissile sandy slate, a rock which is easily fractured. Examples of brecciated wall rocks have been given earlier.

The series of branches "dropping into" the Fortune and Deebles' lodes at the Clifford Amalgamated Mine, and those "dropping into" Trueman's lode in the Gwyn and Singer mine are examples of branches which probably developed as a result of downward movement of the hanging wall.

At Old Wheal Vor there were places where the cleavage planes of the slate of the hanging wall dropped vertically into the lode, and here they had been opened and so filled with cassiterite and "white lithomarge" that the hanging wall for distances up to fifty feet from the fissure was worth working. These cleavage planes were undoubtedly opened as a result of tension produced during the descent of the hanging wall of the parent fissure.

(v) The nature of the faulting associated with lodes. Wherever field evidence is available it almost invariably indicates that fissures associated with lodes and with cross-courses are normal faults, however there is a small amount of evidence to show that reverse faulting has played at least some part on comparatively rare occasions.

Robson is of the opinion that the position of the Great Perran iron lode may have been determined by a thrust, but there is evidence here that at some period normal faulting has taken place as a porphyry dyke intersected by the lode has been displaced in accordance with normal faulting.

Symons has included in his book a section of Wheal Peevor which shows lodes displaced by two reversed faults.

Cronshaw has produced a section of an "end" at the 170 fathom level at the Robinson's section of South Crofty as it appeared in 1915. Here a porphyry dyke is seen to be dislocated by later veinlets in a manner which definitely suggests reverse faulting. This is probably due to inward thrust exerted by the lode walls and therefore of only very local significance.

The author finds the Wheal Peevor example very difficult to accept, for, like Anderson, he believes that "it follows from dynamical theory that thrust planes and normal faults can never occur in association."

There is also a certain amount of evidence to show that lateral displacement along a fault fissure may on occasion have been important in the development of the lode pattern, and that lateral displacement has taken place is undoubtedly proved by evidence given earlier when discussing slickensides.

Le Neve Foster was of the opinion that the East Wheal Lovell tin pipes were determined by vertical openings along which mineralising agents moved, and which were formed largely as the result of one wall of a joint of variable strike moving laterally across the other wall. Fern, writing of the lodes and later barren fissures of Wheal Kitty (St. Agnes) indicated by words and diagrams that in his opinion the displacement suffered by the tin lodes as a result of the development of later faults could only be explained if it were assumed that these later faults were the result largely of lateral movement.

Finally, certain fissures associated with lodes show little or no evidence of being due to faulting.

Hill has stated that some of the Wendron tin lodes show little evidence of vertical displacement of the walls, and the authors of the St. Austell and Bodmin Memoir say that the tin veins of the Beam Mine are not filled fault fissures.

(vi) The importance of faulting in the development of open spaces in fissures. Moissenet was the first to point out that faulting could explain the variation in width of a given fissure and therefore in some cases the positions of ore shoots. He stated that in the development of a fissure, a fracture was first formed, which had, to all intents and purposes no width. If now a section showed this fracture to be a straight line, then even if descent of the hanging wall subsequently took place, no open spaces would be formed. Moissenet was of the opinion that when its fracture was initiated its dip would vary from one type of rock to the next, and then if the hanging wall were depressed open spaces would be formed along those portions of the fissure which had the steepest dips. (Conversely when reverse faulting took place, open spaces would be formed along those portions of the vein with the smallest dips.)

He believed that there was evidence to show that normal faulting had produced open spaces in many of the Cornish lodes, and in support of this he cites, for example, the case of the Main lode at North Roskear, near Camborne, which when dipping south between 80° and 90° showed widths varying from four to seven feet, but when the southerly dip was reduced to between 60 and 64 degrees, the width was reduced to between one and two feet.

His theory is undoubtedly widely held throughout the world to-day, as the following examples will show :— Emmons says that in the Bonanza district of Colorado the ore shoots within the mineralized normal faults are probably due to widening of zig-zag fissures. Hullin states that the Washington vein, which is a normal fault, in the Sunnyside Mine, Colorado, becomes thicker where its dip is steeper. McKinstry has made the following statement — "At Casapalca, Peru, there is a series of veins that vary in dip from vertical to 50° or less. The steeply dipping parts of the system are the widest and richest. The flatter parts are narrow and lean, and where the dip is flatter than 50° the veins are too narrow to mine."

However, it is well to remember that there are plenty of examples of steep dipping portions of lodes which are poor, and that mineralisation of the hypothermal type is often largely confined to the wall rock and in amount seems to bear little or no relation to the width of the associated fissure : some of the largest shoots such as the carbonas of the St. Ives Consolidated mines were associated with very narrow fissures.

Also, cross-courses are more or less vertical, and if Moissenet's theory could be generally applied one would expect to find the greatest amount of displacement associated with the widest cross-courses. However, according to Carne, there is no relationship between width of cross-course and the amount of displacement it has produced, and he cites the following examples in proof of this :—

"In Wheal Virgin (Consolidated Mines) a cross-course two feet wide heaves the lode six fathoms : in Wheal Peevor another of the same width heaves the lode eighteen fathoms ;

at Sparnon a cross-course eight feet wide heaves the lode only two fathoms."

(vii) Intersection and displacement of lodes. Numerous examples exist of lodes intersecting and displacing earlier lodes and dykes, of barren faults intersecting lodes and dykes, and two possible cases have been cited, namely those occurring at Wheal Fortune and at Polgooth, where porphyry dykes may have intersected and displaced veins.

It is convenient to discuss intersections and displacements at this stage under two headings :—

(a) Intersections of lodes by later cross-courses and of lodes by lodes. The magnitude of the displacement of one fissure by another is very variable, but it is probable that the greatest displacements have been brought by the later formed fissures (such as those associated with cross-courses) whose strikes vary by large angles from those of the lodes they displace. Thus, to take an extreme case, the great cross-course of the Camborne-Redruth area, which is nearly vertical, heaves the lodes it intersects from 50 to 70 fathoms and has a downward throw of about 100 fathoms to the east. However, even the displacement produced by the cross-courses is very variable, e.g. "Of 272 lodes traversed by cross veins in different parts of Cornwall, 57, or 20 per cent., are intersected but not heaved. The average displacement of the remaining 80 per cent. throughout the County is sixteen feet."

Of those fissures with similar strikes, which intersect because of variations in dip, displacements of varying magnitudes are met with also.

It is probable that conjugate systems of veins occur in some Cornish localities, such as the Gwyn and Singer Mine, as sections show two systems of intersecting veins dipping in opposite directions but not displacing each other. It is also possible that where one series of veins has been displaced by an opposite dipping series of veins, that the two systems may have been formed at the same time (i.e. conjugate) but that the displacement has been caused by later movement along one set only.

However, a vein probably of considerably later formation than a dyke may intersect the latter without displacing it, and probably the same thing can happen when lodes along are concerned, therefore even when two opposite-dipping systems of lodes intersect each other without displacement it cannot be assumed that they are conjugate unless there is no indication that the lode material of one can be traced through the other.

Economically, the most important result of the intersection of one fissure by another of about the same age is the fact that frequently at the point of intersection rich ore bodies are found, and especially if the lodes in question intersected at fairly acute angles. Such rich bodies were probably due to the mingling of solutions moving along the two fissures combined with stagnation at and near the point of intersection brought about by the very brecciated nature of the ground.

The following are some Cornish examples of rich intersections : At Wendron Consols the junction formed by Liddicoat's and Flanders' lodes was very rich in cassiterite. At Wheal Basset the junctions formed by the intersections of the Great Flat lode and the nearly vertical lodes were generally rich in tin. At East Pool the Main lode has been intersected and heaved by several other lodes with an opposite dip, and at each junction large and valuable ore bodies were found. At West Chiverton the coming together of Williams', Elizabeth's and Valpy's lodes formed great ore shoots.

(b) Intersections of dykes by lodes. A variety of structural patterns may be developed when a lode meets a porphyry dyke and this was made the subject of a paper by Carne, who noted most of the following patterns :—

The lode intersects the dyke and displaces it — (Tolvaddon).

The lode on entering the dyke is completely unaltered — (Weeth copper mine, Gwinear).

The lode on intersecting the dyke splits up into a few or numerous veins which are possibly controlled by the joints of the dyke, and re-unites on passing out of the other side — (Crenver & Abraham).

The lode diminishes in width and value on passing through the dyke — (Carn Brea), (Rosewall Hill).

The lode increases in width and value on passing into the dyke (Wheal Alfred).

The lode on entering the dyke increases in size and value and also sends off numerous small veinlets (possibly controlled by the joints) into the dyke — (Wheal Vor).

The lode on entering the dyke is deflected in such a manner that it appears to be faulted by the dyke.

The lode stops at the dyke.

(viii) Other structural characteristics associated with some Cornish lodes and probably related to faulting.

(a) Sheeted structure. Many valuable lodes are associated with several narrow, closely spaced, parallel fissures along some or all of which the mineralising solutions or vapours which deposited cassiterite, etc., in the walls, moved. Sometimes several of the fissures seem to be equally concerned with the wall rock mineralisation, but in other cases there appears to be a master fissure with which are associated several parallel unimportant fissures in the foot and/or hanging walls.

Such patterns, known as sheeted structures, may be the result of several closely spaced fissures formed contemporaneously, or developed as a result of the stress set up during the downward displacement of the hanging wall of an initial fissure, or as a result of re-opening of the country rock rather than the re-opening of the initial fissure.

Examples of Cornish sheeted structures were seen at Dolcoath, Cook's Kitchen, Ruby Iron Mine (St. Austell), and Penhall's Mine, St. Agnes.

(b) Ribbon and Book Structures. When a series of fissures are so closely spaced that portions of country or fault clay are separated by fissures wider than the included portions of country rock or fault clay, the composite lode is said to possess a "Book" structure.

Examples : At Carn Marth a copper lode in the granite is made up of a series of fissures separated by ribbons of fault clay, being re-openings associated with normal fault movement ; at Fowey Consols Mine the lode developed as a result of the opening of a series of parallel fissures along planes coincident with the cleavage of the slate.

(c) Horses. When a lode splits and re-unites, the included portion of country rock is known as a horse. The development of a horse may be associated with the descent of the hanging wall of a fissure, and local variations in physical property of the country rock.

Horses may also be regarded as being the products of the initial stages of the process which, if carried to completion, would lead to the development of a brecciated lode.

Horses are not infrequently met with in the Cornish lodes, as at Dolcoath (425 fm.), and W. Chiverton (100 fm.).

(d) Patterns exhibited by the lode-dyke, etc., systems in transverse section. The patterns developed in transverse section are made up of two or more of the three components : major intrusives, minor associated intrusives, and other filled fissures. The variations in age, strike and dip of the filled fissures, combined with the fact that most of the mineralised and later fissures are definitely associated with normal faulting, are the other factors which have contributed towards the build-up of the numerous patterns found in Cornwall : these are further complicated by mineralogical patterns which were superimposed upon them.

It is clearly impracticable to do more than to indicate certain of the commoner patterns and motifs commonly incorporated in the more complex patterns and to give a description of the very anomalous types.

i.— A system of parallel veins, each with a constant dip.

This pattern is found in the centres of some of the major granite outcrops and probably represents the roots of lodes which developed from faulted joints. The regularity of dip is probably largely a function of the mechanical homogenity of the granite. Examples are to be found at Ding Dong, New Balleswidden and St. Michael's Mount. A variation of the above is to be found at Cligga (near Perranporth) where a system of parallel cassiterite-wolfram veins each showing great variation in dip, have probably been developed along joints parallel to the original contact, which were probably initiated and opened as a combined result of stresses set up by contraction of the granite during cooling and of gravity. This deposit might well be called a pseudo-bedded deposit.

ii.— Conjugate systems.

These have been described earlier and the theory of their formation later.

iii.— Intersections of lodes dipping in one direction by dipping in an opposite direction.

These have been described earlier.

iv.— Branching lodes.

Branching of lodes in Cornwall is probably dependent on the following factors :—(1) joints and cleavage planes ; (2) faulting ; (3) variations in the mechanical properties of the rocks being fissured.

It is probable that the Cornish lodes are largely dependent upon joints formed during the emplacement of the granite and its subsequent cooling phase. These joints not only affected the granite, but also the country rock, and it is probable that under certain circumstances when a joint cut across a pre-existing joint in the country rock that during the phase of faulting along one, both would tend to be opened. Similarly, cleavage planes, as mentioned earlier, tend to be opened up during the phase of faulting of a joint crossing them. Those cleavage planes which drop steeply into the hanging wall side of the joint are those most likely to be opened, and the Wheal Vor case has already been cited. However, Le Neve Foster has produced sketches of lodes in the St. Agnes Mines where it appears that cleavages in both hanging and foot walls have been opened up and the openings so formed filled with quartz, etc. Perhaps the best example was to be found at the Park of Mines where N.-S. veins cut slates whose cleavage planes strike E.-W. and which dip steeply N. From the N. and S. "leaders" numerous short E.-W. cassiterite and quartz bearing branches are to be found following the cleavage planes of the slate.

The development of extensive branches accompanying the downward displacement of the hanging wall has been discussed earlier.

Branches may develop as a fissure is traced from one rock to another and examples have already been cited in support of this when dealing with the patterns developed when lodes intersect porphyry dykes. The fact that dykes are sometimes shattered by intersecting fissures and at other times cleanly broken is obviously dependent not only on the "brittleness" of the dyke but also on the intensity of the applied force producing the initial joint, the degree of movement which later took place along the plane of the fracture, combined with the presence or absence of tension operating across the fissure. In the opinion of the author, tension joints should show little or no wall rock brecciation.

As a further example of the variations in branching met with as a fissure traverses various types of rock, the author would cite a case at the base of the Tremearne Cliffs, Porthleven. Here a single vertical fissure carrying quartz and chalcopyrite passes through biotite slate hornfels into a roughly horizontal sill of aplite. Whilst in the aplite it branches profusely, but all branches are cut out at the upper junction of the aplite with overlying biotite slate hornfels. This might also be cited as a Cornish example (and the only one as far as the author is aware) of a blanket vein.

v.— Lode-dyke associations.

Frequently the strike of many lodes in any given area is the same as that of the accompanying dykes, and on occasion, the dyke itself has been fissured and the fissure infilled with lode material. Thus at Wheal Basset, Paddon's lode is largely in a dyke, and Paddon's Branch entirely so.

On other occasions a fissure has been opened between the wall of the dyke and the country rock and infilled with lode material. A lode occupying such a position occurred at Red Moor Mine. In many localities also lodes are known which not only strike parallel to the accompanying dykes but also dip parallel to them.

vi.— Lode dipping parallel to the granite slate contact.

It is to be expected that stresses would be developed in the country rock parallel to the granite contact as a result of its emplacement and within the granite and parallel to its contact as a result of contraction during cooling. It is also reasonable to assume that these stresses might subsequently be relieved by fissuring, and examples of fissures are to be found in such positions in Cornwall.

It is possible that the early formed north-dipping lodes to the north of, and parallel to, the granite boss of Carn Brea, fall into this category.

At Cape Cornwall a lode is found at the contact of the granite and the andalusite-slate country rock.

vii.— Stockworks (and closely related bodies).

Stockworks found in the hanging walls of lodes, and their formation have already been discussed.

It is probable also that stockworks, and structures which though somewhat similar to the former, differ from them in that the multitude of veins tend to possess a common strike direction and which therefore may be called "closely sheeted bodies," may develop by processes, to be discussed later, in country rock immediately overlying elevated cupolas, and especially, according to Hulin, chonoliths.

An example of a true stockwork fitting into this category is that of the Fatwork open work near Indian Queens. Here a zone of tourmaline slate about 15 fms. wide, and striking E.-W. is penetrated by a host of short veins carrying cassiterite, quartz and tourmaline "which are also frequently observed traversing the rock in various directions."

An example of a closely sheeted structure belonging to this category is situated at Mulberry, Lanivet.

Stockworks and closely sheeted bodies occurring in porphyry dykes have been worked in Cornwall. These have sometimes been formed as a result of intersection of a dyke by a lode, but on other occasions it appears that the dyke, having been shattered was itself the channel-way for the mineralising solutions.

An example of the former type was found at Wheal Vor and appears to have been a true stockwork. An example of the latter type was found at Wheal Jennings (Parbola) in the parish of Gwinear where numerous tin bearing branches, striking mainly in one direction, were found in a porphyry dyke. These small tin veins mostly pass across the dyke from wall to wall but some extend into the slate. Seymour regarded the veins as shrinkage fissures which were later infilled by means of tin-bearing solutions.

III. THE PATTERN EXHIBITED BY LODE-DYKE SYSTEMS IN PLAN, AND THEORIES OF ITS DEVELOPMENT.

(A) Major existing theories of fissure pattern development associated with granite intrusives.

In the major theories which have been postulated to explain the fissure patterns associated with granite intrusions, the mechanisms invoked are either regional stress, or gas pressure developed within the intrusive, or contraction of the cooling intrusive.

(1) Ghosh's "Regional Stress Theory" of the formation of joints and fissures associated with Carn Menellis granite,

The following is an outline of Ghosh's interpretation of phenomena associated with Carn Menellis granite :—

i. The region was thrown up into a series of anticlines and synclines by Hercynian stresses acting in a N.N.W. direction. These folds were superimposed upon existing structures, and at the same time E.N.E.—W.S.W. cleavage was developed in the country rock .

ii. The magnitude of the pressure increased and was instrumental in bringing about the emplacement of the granite in the earlier-formed anticlines.

iii. The magma, entering the anticlines, exerted a centrifugal hydraulic pressure, which, especially in the east, brought about the development of local cleavage within the metamorphic aureole. At the same time it altered the strikes of the aureole beds and dolerite sills so that they, like the local cleavage, roughly follow the contact of the granite and the country rock.

iv. Whilst the granite was still in a semi-plastic state a crustal pressure operated along an E.N.E.—W.S.W. direction and was followed or accompanied by tension at right angles to it.

These two factors caused the development of E.N.E.—W.S.W. and N.N.W.—S.S.E. joints. At about the same time tension produced by gravity produced the "horizontal" joints which were approximately parallel to the contact. The E.N.E.—W.S.W. joints are regional joints and parallel to the dykes and tin-copper veins of the district, and are found in both the granite and the country rock. In the northern part of the granite, they dip S., towards the centre of the granite the dip increases until it is vertical, and from the centre to the southern margin the dip is N. according to the Cloos' theory they are Q (tensional) joints. The N.N.W.—S.S.E. joints are regional joints and both in the granite and in the country rock they are nearly vertical. These joints are closed, usually barren, and often parallel to the fluxion (alignment of the felspar crystals). According to Cloos' theory they are S joints resulting in this case from "a directed lateral pressure acting in a roughly east and west direction simultaneously with the north and south tension to which the roughly east and west Q joints are due." The horizontal joints which include the "pseudo-bedding planes" are distinctly related to the granite contact. Their dip is variable excepting on the granite margins where they invariably dip towards the country rocks, and the vertical distance between these joints increases with depth. Cloos (and Ghosh) believe such joints to have been developed by gravitational tension which operated during the period of consolidation of the granite.

v. The granite became solid ; the Q joints were filled with dykes and mineral deposits and some diagonal (or Mohr's) joints were initiated as a result of pressure and tension acting along the same lines as those which caused the development of the Q and S joints in the semi-plastic granite.

vi. A little later, a pressure acting along a N.N.W.—S.S.E. direction, and accompanied by a tension at right angles to it, produced the remainder of the diagonal joints, and the late and often barren N.N.W.—S.S.E. fissures known as cross-courses.

Diagonal joints in the Carn Menellis mass occur as conjugate sets which may be either vertical or low dipping. These are believed by Ghosh and others to have been due to pressure along a line accommodated by the acute angles of the diagonal joints, together with tension at right angles to it.

As the acute angles of the Carn Menellis diagonal joints accommodate sometimes the one master joint and sometimes the other the pressure must have varied in its direction.

In the Carn Menellis region the diagonal joints are sometimes better developed than the Q and S joints.

When the diagonal joints are low dipping they are parallel to either the Q or S joints and when their dip is vertical their strike is 40 to 50 degrees oblique to the strike of the Q and S joints.

(2) Emmons' "Gas-Pressure" Theory.

Emmons, as a result of examination of the plans and other data relating to the majority of the mine fields of the world associated with acid intrusives, is of the opinion that the strike patterns of the lodes developed in such areas are a function of the shape (in plan) of the intrusives with which the lodes are associated. Thus a cupola which is circular in plan tends to have a radial vein pattern, whilst an elongated body tends to have a system of veins striking parallel to its long axis associated with it. The vein pattern may diverge somewhat from the ideal by the contemporaneous development and mineralisation of fissures along pre-existing lines of weakness which may show no relationship to the shape in plan of the associated intrusive.

Furthermore, Emmons believes that the fissures were initiated as follows :—Following the emplacement of a given body of granite, and by reason of cooling, a solid "hood" formed. At a certain temperature in the crystallisation of the magma beneath the hood a great deal of gas consisting largely of steam was liberated and collected beneath the hood where it finally exerted sufficient pressure to fracture, not only the overlying granite, but also the country rocks above. By slumping along the fractures thus created, fissures were formed which became infilled with minerals. This process of rupture he believes to be capable of repetition, provided the earlier formed fissures are sealed by deposited minerals and fault detritus.

The mechanism postulated by Emmons is based on experiments made by Morey and Goranson : Morey observed the pressure phenomena associated with the cooling of the system H_2O, 9.1% ; K_2O, 17.3% ; SiO_2, 73.6% ; enclosed in a bomb. This system was fluid at 500° C. and exerted no vapour pressure, but on cooling to 400° C., a large portion crystallised and a great deal of water was liberated from the system as steam, which had a pressure of 4,998 lbs. per sq. inch, "a force sufficient to lift nearly a mile of granite."

Goranson, working on similar lines to Morey, found that an albite-water system cooling from 1,100° C. generated a vapour pressure during crystallisation sufficient to lift about ten miles of granite.

Finally, Emmons believes that there is a "dead-line" below which fissures are barren, and which may be in the region of two miles below the granite country rock contact, and that the reason why the centres of many granite outcrops are barren of lodes is because they have been eroded to below this dead-line.

(3) Hulin's "Contraction" Theory.

Hulin has based his theory of fissure formation associated with acid intrusives largely on the following facts :—

i. Experimental data indicates that it is probable that fluid granite in changing to the solid rock would suffer a volume decrease of about 10%, and that the solid granite would then suffer a further 6% decrease in volume as a result of thermal contraction.

ii. From calculations based on the "helium number" made by Urry when working on the rocks of Grass Valley, California, it appears that a time limit of at least three million and possibly as much as twelve million years may have elapsed between the crystallisation of the granodiorite there and the onset of the attendant mineralisation.

iii. Fissure veins show a direct relationship to the shape in plan of the intrusive with which they are associated.

iv. Progressive faulting over a long period is necessary for the development of a mineralised area.

Hulin visualised the emplacement of an acid intrusive and the development of associated fissure veins, etc., to have taken place as follows :—

(a) The granite was emplaced along pre-existing lines of weakness.

(b) The force of intrusion caused fractures to develop in the overlying rock which may have controlled the position of batholith "roof structures" such as cupolas, chonoliths, etc., and these latter, during their emplacement caused further fracturing of the rocks over them.

(c) The batholith roof as a whole slowly subsided as a result of contraction, but at a much later stage those portions of the roof which were above partially filled magma reservoirs became unstable and collapsed. This collapse also affected the firmly attached country rock above those portions, so that both granite and country rock were faulted and the fault fissures were filled with differentiated magmatic material which consolidated as dykes.

(d) The extreme state of differentiation shown by the magma at this stage, combined with the experimental work of Urry on the relative times of formation of major and associated minor intrusives indicate that the magma was by this time very deep seated, and therefore the still later mineralising solutions must also have come from very deep seated sources, and were therefore not directly associated with the bosses, etc., with which the fissure veins appear to be closely connected. This is in direct opposition to Emmons' theory.

Faulting was at a maximum during this period due to the fact that the temperature gradient between the granite and the country rock was then greatest and also because the thermal contraction of minerals is much greater at elevated temperatures than at low temperatures. Faulting continued, nevertheless, throughout the ensuing period of mineralisation but became progressively less pronounced. The fact that the granite and the country rock were firmly attached to each other, caused faulting to extend through both rock types.

Contraction under the conditions in question tends to produce a series of *potential* contraction joints surrounding the intrusive like shells due to the fact that the volume change is likely to be greatest as the intrusive is approached, for here the initial temperatures were highest. This variation in volume change with distance from the intrusive is probably as effective in promoting structural disturbances as is the actual magnitude of the volume change.

The potential shells mentioned above would not develop as the stresses would largely be taken up along pre-defined faults, thus leading largely to continued movement along already developed fissures.

Finally, entirely unrelated periods of igneous activity and of faulting may be superimposed upon the mineralised district. These merely modify the features already developed.

Hulin is also of the opinion that fairly small but highly fissured mineralised areas have been formed in the country rocks above chonoliths in the following way :—The narrow portion of the chonolith consolidated and thus permitted contraction associated with solidification of the portion above the constriction to bring about a great deal of fissuring not only of the chonolith but also of the rock overlying it.

If the intrusive had been conical, in the words of Hulin, "volume shrinkage as crystallisation took place would be automatically compensated by upward movement of magma from below. Thus, though volume change due to change of state was actually occurring, it could produce no useful result."

The essence of Hulin's theory is that in his opinion the grouping of ore deposits in mineralised districts in close proximity to intrusive igneous bodies is dependent on structural control resulting from forces set in operation by the intrusive bodies, and these forces are largely due to contraction of the rocks concerned.

(4) Other theories of fissure formation which have been thought to be applicable to the West of England.

Daubree's Theory.

Daubree twisted a thick piece of glass and thus produced in it two sets of joints approximately at right angles to each other.

Some have suggested that similar torsional stress might account for the Cornish fissures, as in almost any given area two sets of fissures with strikes differing by large angles exist. However, the age of formation of these two sets of fissures, is very different and therefore cannot be compared with torsional joints developed in glass. Furthermore, Leith and Meade have shown that torsional joints do not extend through any great thickness of substance, whilst Becker has shown that the fissures developed in glass by torsion are curved and warped, and generally unlike vein fissures.

Brammall's Theory.

Brammall has suggested that some of the fissures containing quartz and tourmaline in the kaolinised granite of Dartmoor were developed as a result of contraction due to change in volume as a result of the kaolinisation process. As there is considerable evidence to show that tourmaline is a high temperature mineral, and Kaolinite a much lower temperature and later-formed mineral, this theory does not seem sound.

(B) Cornish fissure pattern in plan.

Though a given lode is frequently represented as a straight line on a small scale map, in point of fact it is often extremely sinuous as a large scale plan of any mine will show. Thus, at

Geevor mine for example, the lodes, especially the North and South Pig Lodes, have very sinuous strikes, and Thomas as a result of careful study of the varying strike directions met with in the Dolcoath Main lode, was of the opinion that "changes in the bearings of the lodes appear to be the chief cause of productiveness or otherwise." This fact may to some extent be related to the development of open parts in the lodes by lateral displacement of the walls.

In any given area of Cornwall, the lodes may show a variety of strikes, but they can usually be divided into two groups whose strikes differ by large angles. Also the average strike of these two major groups varies from district to district, a fact clearly realised by Henwood, who compiled the table below :—

Districts	Lodes	Cross-veins	Difference
St. Just	35° S. of E.	26° N. of E.	61°
St. Ives	8° S. of E.	38° S. of E.	30°
Marazion	1° N. of E.	41° S. of E.	42°
Gwinear, etc. ...	2° S. of E.	47° S. of E.	45°
Helston	16° N. of E.	21° S. of E.	37°
Camborne, etc. ...	20° N. of E.	56° S. of E.	76°
Redruth, etc. ...	22° N. of E.	35° S. of E.	57°
St. Agnes	22° N. of E.	51° S. of E.	73°
St. Austell ...	13° N. of E.	21° S. of E.	34°
Caradon	18° N. of E.	77° S. of E.	85°
Callington ...	—	43° S. of E.	—
Tavistock	9° N. of E.	—	—

However interesting such data may be, it does not give an overall picture of the fissure pattern of Cornwall, which is only obtained from a map of fairly large scale from which the following facts emerge :—

i. In any given area, some fissure lodes and dykes strike along parallel lines, but there is always a set of fissures intersecting these at a fairly large angle. This is in accordance with Henwood's table given above.

ii. Many veins and dykes are associated with fringes of the granite outcrops, but comparatively few are encountered in the centres of these outcrops. This barrenness may be due to some extent to the removal by erosion of once existing lodes as suggested by Emmons, but there is another possible explanation which will be discussed later.

Certain marginal portions of the granite outcrops are practically, if not entirely, devoid of fissure veins, and this, for example, is true of the southern portion of the Land's End granite and the south-eastern portion of the Carn Menellis granite.

iii. Many dykes and some parallel tin-copper lodes are quite far removed from any visible granite. This is true of the dykes and tin-copper lodes of the Gwinear district and of the tin lodes near Perranporth.

iv. In many cases the lode-dyke pattern bears little or no relationship to the shape in plan of any granite outcrop with which it appears to be associated. Two notable exceptions occur :—The lodes of the Land's End area show a roughly radial arrangement, the fact noted by Emmons and utilised by him as an example of the radial development of lodes associated with circular granite intrusions. The elongated boss of Carn Brea has lodes and dykes striking parallel to its long axis. This also according to Emmons is just the pattern which would be expected.

v. Throughout the county very marked "streams" of lodes and associated dykes can be seen. Thus, in the area between the Penzance fringe of the Land's End granite and the Godolphin mass, a series of lodes and dykes swings round in an arc approximately parallel to the coastline. Another series swings round in a broad arc from St. Agnes through Cligga and Perranporth to just south of the St. Austell granite-slate contact, and another marked stream "flows" across the southern marginal portion of the Bodmin Moor granite and on through Kit Hill and Hingston Downs to Dartmoor.

(C) Author's Theory.

(a) Evidence that the dykes and earlier lodes are controlled by granite ridges.

If the cross-courses are ignored, the lode-dyke pattern of Cornwall becomes a rational one if it is assumed that the strikes of both dykes and earlier lodes are controlled by granite ridges. This in essence Emmons, Hulin, and others believed to be the case generally throughout the world as far as mineralised fissures associated with granite and intermediate intrusives are concerned. W. D. Johnson and Cloos, for example, have put forward a theory on these lines to explain the lode pattern of Grass Valley, California.

It is held by the author that the earlier Cornish lodes and dykes strike parallel to the long axes of the granite ridges which generally only appear at the surface where pre-existing doming due to the combined action of Variscan and Armorican earth movements have locally allowed a great mass of granite to be emplaced at a higher level than that pertaining elsewhere.

Moreover, the following facts are strong evidence for the existence of such ridges :—

i. At Gwinear Church Town spotted slate occurs in the vicinity of the village, and according to Collins, in Gwinear Consols smooth masses of granite of several pounds in weight were met with in the lode at 100 fathoms and at a distance of nearly three miles from the nearest granite outcrop. Masses of granite were also found in the lodes of Trevaskus Mine, all in the Parish of Gwinear.

ii. At Godrevy the author has found a patch of spotted slate of contact metamorphic origin in the low land near the Red River. This was laid bare during the time that the dune sand was being worked for cassiterite. Spotting occurs in the slates of Godrevy cliff but these are not of contact metamorphic origin. The area is about four miles from the nearest granite outcrop.

iii. In 1922 Davison saw at Bridge Quarry, Illogan, a large block of granite included in the porphyry. "It showed no signs of fusion along the contact of the quartz-porphyry and could not have travelled far." The quarry is about two miles from the Carn Brea granite outcrop.

iv. The large extent of the metamorphic aureole of St. Agnes and Cligga, when compared with the associated granite outcrops, and its position suggests that the granite extends to the north at comparatively shallow depths. This is further confirmed by the fact that cassiterite has been worked in the sand dune area to the north of Perranporth at a distance of 2½ miles from Cligga which is the nearest granite outcrop.

v. At Tehidy (about 2½ miles north of Camborne) a lode carrying 20 lbs. of cassiterite to the ton exists. This lode is about 2½ miles from Carn Brea which is the nearest granite outcrop.

Similarly cassiterite has been mined at Relistian, Trevaskus and Parbola (Gwinear), and at Wheal Jane in the St. Day area. All these places are at least two miles from the nearest granite contact, and as cassiterite always occurs in or near the granite, the latter must be at comparatively shallow depths in these areas.

vi. At Wheal Budnick near Perranporth, cassiterite is found in a rock which is usually termed a porphyry but which has a granitic texture and may therefore be the thin back of a granite ridge extending towards the St. Austell mass.

vii. Cassiterite has been reported from a quarry near Mitchell, which is at a distance of four miles from the St. Austell granite mass.

viii. A quarter of a mile S.W. of Relubbus and about two miles from the Godolphin granite the author has found portions of a granite pegmatite on a small mine dump. This is clear indication that granite must exist at comparatively shallow depths.

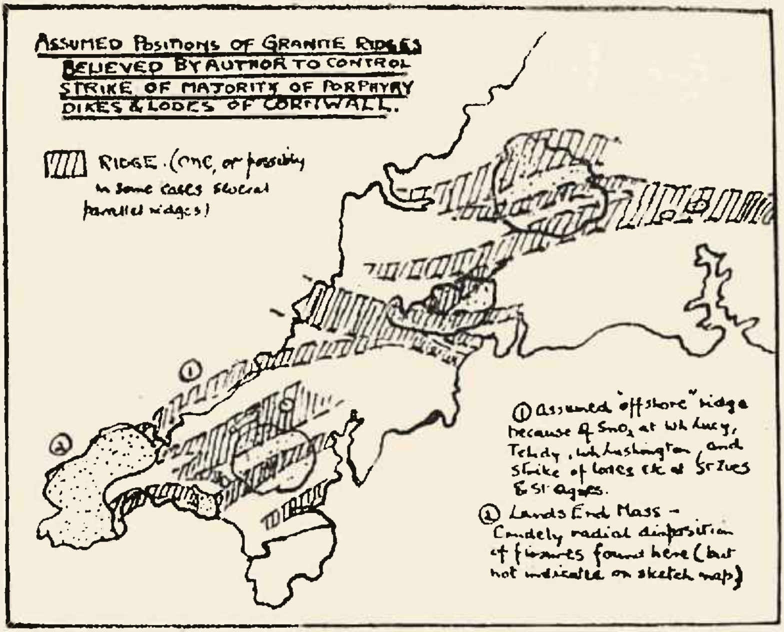
ix. Finally, a ridge has been shown by mining development to exist to the north of Carn Brea and MacAlister has made the following remarks about it : "The subterranean ridge of granite seen at Camborne Vean Mine is also found at Dolcoath, South Crofty, East Pool, and, presumably, Wheal Tehidy, along a line bearing approximately E. 20° N. In nearly all its course the hollow between the ridge and the main mass is associated with parallel elvan dykes or lodes."

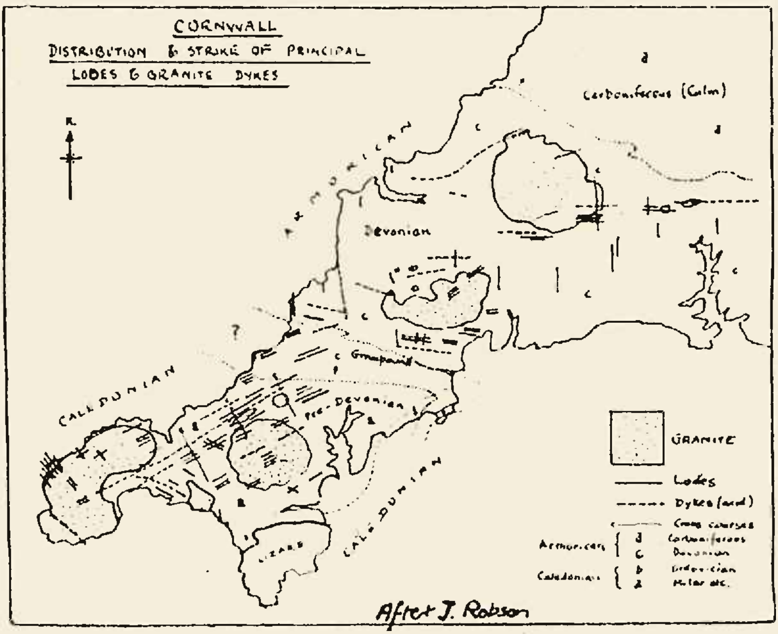
These ridges would appear to be controlled in the west largely by the effects of Variscan earth movements, and in the east largely by Armorican earth movements. Their positions are shown on the map.

Furthermore, these ridges probably have an undulating profile, an idea which is indicated by the granite outcrops of Kit Hill and of Hingston Downs. These are probably the highest portions of the ridge extending from Bodmin Moor to Dartmoor. The pattern developed here is reminiscent of that of the tin-tungsten area of Hermyinghi, Burma, about which Emmons writes as follows : "They (i.e. the lodes) are very closely associated with the smaller bodies of granite and are found also in belts that lie between the small cupolas of the granite where there is probably a buried ridge of the roof of the parent granite mass."

It is also believed by the author that a ridge "runs" from the Lelant-Carbis Bay area via Hayle Towans, Gwithian, Tehidy, Portreath, St. Agnes, Cligga, Budnick to St. Austell, and, that this ridge has an undulating profile is to some extent indicated by the isolated occurrences of cassiterite at Hayle Towans, Tehidy, Wheal Lushington, St. Agnes, Cligga, Budnick and Mitchell ; separated by areas where only lower temperature minerals have been encountered.

It is to some extent also possible to trace the roots of ridges across the larger outcrops, and therefore it seems possible that the lack of mineralisation in some of these areas may


ASSUMED POSITIONS OF GRANITE RIDGES BELIEVED BY AUTHOR TO CONTROL STRIKE OF MAJORITY OF PORPHYRY DIKES & LODES OF CORNWALL.
RIDGE. (one, or possibly in some cases several parallel ridges)
① Assumed "offshore" ridge because of SnO_2 at Wh Lucy, Tehidy, Wh Lushington, and strike of lodes etc at St Ives & St Agnes.
② Lands End Mass – Crudely radial disposition of fissures found here (but not indicated on sketch map)


CORNWALL
DISTRIBUTION & STRIKE OF PRINCIPAL LODES & GRANITE DYKES
N.
Carboniferous (Culm)
ARMORICAN
Devonian
CALEDONIAN
Pre-Devonian
CALEDONIAN
LIZARD
GRANITE
Lodes
Dykes (and)
Cross courses
Armorican { d Carboniferous
c Devonian
Caledonian { b Ordovician
a Hilar etc.
After J. Robson

not altogether be due to the fact that erosion has gone on to below the lode dead-line, but rather, that in certain areas, ridges along which mineralisation took place did not exist.

(b) Author's views of the history of fissure development in Cornwall.

The author believes that the fissure pattern is largely controlled by regional stresses acting as postulated by Ghosh, combined with the contraction of the granite and attendant slumping under gravity.

In this theory it is necessary to accommodate two or even three phases of mineralisation. The Castle-an-Dinas area certainly shows the products of metallisation which is sandwiched (probably) between two periods of granite intrusion, and is possibly of earlier age than the main period of metallisation in Cornwall. On the other hand the distinct possibility of a period of metallisation later than the major period is indicated at South Crofty, but here as far as the meagre information goes, the later lode strikes in the same direction as lodes of the main period of metallisation, and so differ from the Castle-an-Dinas area lodes which have an anomalous strike.

The history then of the fissure development may have been as follows :—

i. Emplacement of the granite which gave rise to the Castle-an-Dinas lode (not the granite which now appears in Castle-an-Dinas Mine).

ii. Directed S.-N. regional pressure causing the development of N.-S. Q or tensional joints, and S or compression joints at right angles. Both these systems were developed on a regional scale. The S joints may have constituted planes of weakness which were opened up after the major period of granite intrusion and infilled by the roughly E.-W. dykes of the Withiel district and some lodes, notably the roughly E.-W. cassiterite lode just to the west of Lanivet.

iii. Formation of contraction fissures and slumping and emplacement of the Watergate Bay and the Mount Joy dykes.

iv. Continued faulting and the development of the N.-S. striking cassiterite and wolfram lodes, and in the case of the Mulberry area, slumping over a chonolith.

v. Emplacement of the major Cornish granites along lines produced by Armorican folds superimposed upon earlier Variscan folds. Where anticlines of these two systems intersected, knots of granite, now represented by the large outcrops were emplaced, whilst ridges of granite were emplaced largely along Variscan lines in the west and Armorican in the east.

vi. Due to the emplacement of the granite, planes of weakness were formed in the country rock parallel to the sides of the intrusives.

vii. Regional pressure acting along W.S.W. to E.N.E. lines produced the regional Q (open) joints and S (closed) joints. The direction of the Q joints may have been varied in order to accommodate planes of weakness existing parallel to the long axes of the ridges when their strike was not widely different from that of the directed pressure producing the Q joints.

viii. Consolidation of the granite was accompanied by contraction along the Q joints and planes of weakness parallel to the long axes of the ridges and this, attended by gravitational slumping, initiated fissures which were filled by magma forced into them as a result of pressure of the slumping, contracting, semi-solid granitic mass on the fluid residual magma. This injected magma consolidated as porphyry dykes. Also, during consolidation, pockets of magma, rich in fluxing materials, were entrapped in the mass, and these on consolidation became patches of pegmatite, whilst other femic-rich pockets of magma which were entrapped became "basic segregations."

iv. By continued slumping, further fissures were formed and probably old ones re-opened and these were infilled by magma fractions which were becoming progressively more differentiated and are now represented by aplites, minettes, quartz veins, quartz-tourmaline veins and granite pegmatites.

The long period of minor intrusion is perhaps indicated by the fact that some porphyry dykes in the slate have little or no chilled margins (e.g. Watergate Bay) whilst others in the granite have well marked chilled margins (e.g. Carn Brea). Presumably the former type were formed at a fairly early period when the country rock was well heated, whilst the latter were formed at a much later date when even the marginal granite had become fairly cool. Of course the width of the dyke and the quantity of fluxing materials in the injected magma were also factors of importance in this connection.

x. Still further progressive slumping, combined with increased differentiation of the magma residuum caused the development of metalliferous pegmatites and hypothermal lodes of the cassiterite-wolfram-chalcopyrite type striking along lines roughly parallel to the already emplaced dykes. Possibly also some of the galena-sphalerite deposits striking parallel to or occupying the higher horizons of cassiterite type lodes were formed soon after.

Occasionally this period of metallisation may have overlapped the period of dyke formation. This would account for the queried examples of dykes faulting lodes which have been quoted earlier. Of course, another explanation would be that these dykes represent the minor intrusive phase of a later period of granite intrusion for which, as already stated, some slight evidence exists.

At this time also, slumping over elevated bosses or chonoliths may have brought about the development of stockworks and related structures.

By this time also the temperature had dropped sufficiently for contraction to be sufficiently strong to bring about fissure initiation roughly parallel to the granite-country rock contact. Such fissures are well developed to the north of Carn Brea and are earlier than those with the same strike but which dip into the granite.

At this period also the combined action of contraction and gravity opened up fissures in the Cligga granite parallel to this contact. These then became infilled with cassiterite and allied minerals.

xi. When the hypothermal lodes were being formed, those Mohr (or diagonal) joints which were due to pressure acting along the direction of the Q joints were initiated and some of them were probably opened by contraction and slumping and then filled with high temperature minerals. Thus, the conjugate vein systems mentioned earlier are believed to have originated.

xii. Later pressure, acting along the S joint direction caused the remainder of the Mohr joints to develop. Probably it was this pressure which caused tension across the S joints, thus permitting them to be converted into those fault fissures which are now termed cross-courses.

Some of these fissures penetrated sufficiently deeply to tap the magma residum and thus originated the zinc-lead-silver-iron lodes which were followed by later barren quartz veins.

Still later, fissures containing only fault detritus were developed, either because the fissures did not penetrate sufficiently deeply or because the magma residuum had been previously exhausted.

Information is insufficient to incorporate anything here regarding the fissuring associated with the possible later period of high temperature metallisation of the South Crofty Mine, other than that the complex lode which may belong to this later period strikes in about the same direction as the other tin lodes of the mine.

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